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International application number: PCT/US05/023527

International filing date: 01 July 2005 (01.07.2005)

Document type: Certified copy of priority document

Document details: Country/Office: US
Number: 60/615,810
Filing date: 04 October 2004 (04.10.2004)

Date of receipt at the International Bureau: 17 August 2005 (17.08.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)



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APPLICATION NUMBER: 60/615,810

FILING DATE: *October 04, 2004*

RELATED PCT APPLICATION NUMBER: *PCT/US05/23527*



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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. EV 400364165 US

INVENTOR(S)

| | | |
|--|------------------------|---|
| Given Name (first and middle [if any]) | Family Name or Surname | Residence (City and either State or Foreign Country) |
| Yiqun (NMN) | Huang | San Antonio, Texas |

Additional inventors are being named on the 1 separately numbered sheets attached hereto

TITLE OF THE INVENTION (500 characters max)

METHOD FOR THE SIMULTANEOUS DESULFATION OF A LEAN NO_x TRAP AND REGENERATION OF A

Direct all correspondence to:

CORRESPONDENCE ADDRESS

DIESEL PARTICULATE FILTER

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OR

| | | | | | |
|---|-----------------------------------|-----------|-------------|-----|--------------|
| <input checked="" type="checkbox"/> Firm or Individual Name | Ted D. Lee | | | | |
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ENCLOSED APPLICATION PARTS *(check all that apply)*

☒ Specification Number of Pages 25
☐ CD(s), Number _____

☒ Drawing(s) Number of Sheets 3
☐ Other (specify) _____

☐ Application Date Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

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| <input checked="checked" type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27. <input checked="checked" type="checkbox"/> A check or money order is enclosed to cover the filing fees. <input type="checkbox"/> The Director is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number: _____ <input type="checkbox"/> Payment by credit card. Form PTO-2038 is attached. | FILING FEE Amount (\$) <div style="border: 1px solid black; padding: 10px; margin-top: 10px; font-size: 1.2em;">80.00</div> |
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The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

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[Page 1 of 2]

Respectfully submitted,

Date Oct. 4, 2004

SIGNATURE

REGISTRATION NO. 25,819

TYPED or PRINTED NAME Ted D. Lee

(if appropriate)
Docket Number: P-17.164(PRO)

TELEPHONE 210/886-9500

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| Shizuo (NMN) | Sasaki | San Antonio, Texas |
| Gary D. | Neely | San Antonio, Texas |
| Jeffery A. | Leet | San Antonio, Texas |

Number 2 of 2

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16623
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FEE TRANSMITTAL for FY 2004

Effective 10/01/2003. Patent fees are subject to annual revision.

☒ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT (\$) 80

Complete if Known

| | |
|----------------------|-------------------|
| Application Number | |
| Filing Date | |
| First Named Inventor | Yigun (NMN) Huang |
| Examiner Name | |
| Art Unit | |
| Attorney Docket No. | P-17 164 (PRO) |

METHOD OF PAYMENT (check all that apply)☒ Check ☐ Credit card ☐ Money Order ☐ Other ☐ None☐ Deposit Account:Deposit
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| Large Entity | | Small Entity | | Fee Description | Fee Paid |
|--------------|----------|--------------|----------|------------------------|----------|
| Fee Code | Fee (\$) | Fee Code | Fee (\$) | | |
| 1001 | 770 | 2001 | 385 | Utility filing fee | |
| 1002 | 340 | 2002 | 170 | Design filing fee | |
| 1003 | 530 | 2003 | 265 | Plant filing fee | |
| 1004 | 770 | 2004 | 385 | Reissue filing fee | |
| 1005 | 160 | 2005 | 80 | Provisional filing fee | 80 |
| SUBTOTAL (1) | | | | | (\$) |

2. EXTRA CLAIM FEES FOR UTILITY AND REISSUE

| | | | | | | |
|--------------------|---|--------------|---------|---|----------------|----------|
| Total Claims | 9 | Extra Claims | -20** = | X | Fee from below | Fee Paid |
| Independent Claims | 1 | | -3** = | X | | |
| Multiple Dependent | | | | | | |

| Large Entity | | Small Entity | | Fee Description | Fee Paid |
|--------------|----------|--------------|----------|--|----------|
| Fee Code | Fee (\$) | Fee Code | Fee (\$) | | |
| 1202 | 18 | 2202 | 9 | Claims in excess of 20 | |
| 1201 | 86 | 2201 | 43 | Independent claims in excess of 3 | |
| 1203 | 290 | 2203 | 145 | Multiple dependent claim, if not paid | |
| 1204 | 86 | 2204 | 43 | ** Reissue independent claims over original patent | |
| 1205 | 18 | 2205 | 9 | ** Reissue claims in excess of 20 and over original patent | |

SUBTOTAL (2)

(\$)

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FEE CALCULATION (continued)**3. ADDITIONAL FEES**

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| 1051 | 130 | 2051 | 65 | Surcharge - late filing fee or oath | |
| 1052 | 50 | 2052 | 25 | Surcharge - late provisional filing fee or cover sheet | |
| 1053 | 130 | 1053 | 130 | Non-English specification | |
| 1812 | 2,520 | 1812 | 2,520 | For filing a request for ex parte reexamination | |
| 1804 | 920* | 1804 | 920* | Requesting publication of SIR prior to Examiner action | |
| 1805 | 1,840* | 1805 | 1,840* | Requesting publication of SIR after Examiner action | |
| 1251 | 110 | 2251 | 55 | Extension for reply within first month | |
| 1252 | 420 | 2252 | 210 | Extension for reply within second month | |
| 1253 | 950 | 2253 | 475 | Extension for reply within third month | |
| 1254 | 1,480 | 2254 | 740 | Extension for reply within fourth month | |
| 1255 | 2,010 | 2255 | 1,005 | Extension for reply within fifth month | |
| 1401 | 330 | 2401 | 165 | Notice of Appeal | |
| 1402 | 330 | 2402 | 165 | Filing a brief in support of an appeal | |
| 1403 | 290 | 2403 | 145 | Request for oral hearing | |
| 1451 | 1,510 | 1451 | 1,510 | Petition to institute a public use proceeding | |
| 1452 | 110 | 2452 | 55 | Petition to revive - unavoidable | |
| 1453 | 1,330 | 2453 | 665 | Petition to revive - unintentional | |
| 1501 | 1,330 | 2501 | 665 | Utility issue fee (or reissue) | |
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| 1503 | 640 | 2503 | 320 | Plant issue fee | |
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| 1806 | 180 | 1806 | 180 | Submission of Information Disclosure Stmt | |
| 8021 | 40 | 8021 | 40 | Recording each patent assignment per property (times number of properties) | |
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| 1801 | 770 | 2801 | 385 | Request for Continued Examination (RCE) | |
| 1802 | 900 | 1802 | 900 | Request for expedited examination of a design application | |

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SUBTOTAL (3)

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(Complete if applicable)

| | | | | | |
|-------------------|------------|-----------------------------------|--------------|-----------|--------------|
| Name (Print/Type) | Ted D. Lee | Registration No. (Attorney/Agent) | 25,819 | Telephone | 210/886-9500 |
| Signature | | Date | Oct. 4, 2004 | | |

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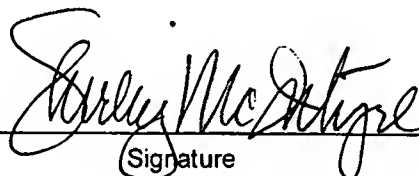
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1. Provisional Application for Patent Cover Sheet
2. Fee Transmittal
3. Specification
4. Drawings
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Provisional Patent Application
Inventors: Yiqun Huang, et al.
Assignee: Southwest Research Institute
Atty. Docket No.: P-17.164PRO)

**IN THE UNITED STATES
PATENT AND TRADEMARK OFFICE**

TITLE:

**METHOD FOR THE SIMULTANEOUS DESULFATION OF
A LEAN NO_x TRAP AND REGENERATION OF
A DIESEL PARTICULATE FILTER**

INVENTORS:

**Yiqun Huang
Shizuo Sasaki
Gary D. Neely
Jeffery A. Leet**

BACKGROUND OF THE INVENTION

Technical Field

This invention relates generally to a method for removing sulfur from a lean NO_x trap while simultaneously regenerating a Diesel particulate filter, and more particularly to such a method that controls the duration and frequency of engine operation in a rich combustion mode concurrently with control of the air/fuel ratio to provide the high temperature requirements of lean NO_x trap desulfation and the oxidation of particles trapped in a Diesel particulate filter .

Background Art

Worldwide emissions regulations slated for introduction in the near future impose very stringent emissions regulations. The Tier 2 regulations in the United States require that Diesel vehicles have the same ultra-low emissions levels as spark ignited vehicles. Combustion mode changes, to address both in-cylinder (engine-out) and exhaust gas treatment device requirements have been proposed. For example, U.S. Patent No. 5,732,554, issued March 31, 1998 to Shizuo Sasaki, et al. for an *EXHAUST GAS PURIFICATION DEVICE FOR AN INTERNAL COMBUSTION ENGINE* describes a method by which the normal fuel lean operating mode of an engine is switched to a rich premixed charge compression ignition (PCCI) combustion mode.

1 U.S. Patent No. 5,937,639 granted August 17, 1999 to Shizuo Sasaki, et al. for

2 *INTERNAL COMBUSTION ENGINE* describes an alternative method for lowering the
3 combustion temperature, i.e., low temperature combustion (LTC) to minimize smoke
4 generation during rich, or near rich, combustion. LTC and PCCI combustion are
5 alternative combustion modes which normal Diesel lean combustion can be transitioned
6 to during engine operation.

7 Perhaps of most concern to the Diesel engine market are the proposed very tight
8 future reductions in terms of oxides of nitrogen (NO_x) and particulate matter (PM)
9 emissions. One of the most promising technologies for NO_x treatment are NO_x
10 adsorbers, also known as "lean NO_x traps". Diesel particulate filters, also known as
11 Diesel particulate traps, and lean NO_x traps are the most likely, at least in the
12 foreseeable future, means by which emissions will be reduced. Lean NO_x traps and
13 Diesel particulate filters need to be regenerated periodically to restore their efficiencies.
14 The regeneration of lean NO_x traps is usually done by providing reductants, such as CO
15 and HC under oxygen-free conditions. A regenerated lean NO_x trap not only adsorbs NO_x
16 emissions, but also adsorbs sulfur carried in the exhaust gas stream. Sulfur removal
17 (desulfation) must be undertaken at a temperature above 600°C under oxygen-free
18 conditions, i.e., a stoichiometric or richer air/fuel ratio. Under typical Diesel lean

1 combustion operation, such very high temperatures cannot normally be obtained except
2 under very high load conditions. Diesel particulate filter regeneration is carried out by
3 oxidizing soot and other particles "trapped" in the Diesel particulate filter at a high
4 temperature and a lean air/fuel ratio.

5 Thus it can be seen that both desulfation of a lean NO_x trap and regeneration of
6 a Diesel particulate filter require very high temperatures. However, typical Diesel
7 combustion cannot provide high exhaust gas temperatures because the engine operates
8 with a lean to very lean combustion mixture. Heretofore, post-injection or in-exhaust
9 injection has been used to obtain the required aftertreatment device regeneration
10 temperatures. Post-injection can result in undesirable oil dilution due to wetting of the
11 cylinder liner, and in-exhaust injection requires extraneous hardware. Moreover, the
12 desulfation process requires a substantially oxygen free atmosphere, whereas Diesel
13 particulate filter regeneration is an oxidization process. Heretofore, these conflicting
14 requirements have, of necessity, been carried out in separate operations.

15 The present invention is directed to overcoming the problems set forth
16 above. It is desirable to have a method by which desulfation of the a lean NO_x trap
17 (LNT) is carried out concurrently with oxidizing trapped particulate matter in a Diesel
18 particulate filter (DPF).

SUMMARY OF THE INVENTION

In accordance with one aspect of the present invention, a method for simultaneously removing sulfur from a lean NO_x trap and regenerating a Diesel particulate filter comprises identifying when desulfation of a lean NO_x trap associated with the engine is required, and then determining a desired rich combustion mode for temporary operation of the engine. The substrate temperature of the lean NO_x trap is sensed and the temperature of the exhaust gas prior to the exhaust gas passing through a turbocharger associated with the engine is also sensed. The engine is operated in alternating lean and rich combustion modes for respective predefined periods of time. The respective periods of time are of a frequency and duration that is sufficient to increase the substrate temperature of a lean NO_x trap to a temperature at which sulfur accumulations stored in the lean NO_x trap is reduced and the Diesel particulate trap is simultaneously regenerated.

Other features of the method for simultaneous lean NO_x trap sulfur removal and Diesel particulate filter regeneration include controlling the air/fuel ratio and the frequency and duration of time of operation in the alternating rich combustion mode to prevent the sensed temperature of exhaust gas prior to passing through the

1 turbine stage from exceeding a predefined value.

2 Another feature of the present invention includes determining that the engine
3 is operating in a predefined relatively low load region of the engine operating range
4 and then operating of the engine between alternating lean and rich combustion
5 modes includes alternately operating the engine respectively in a lean low
6 temperature combustion mode and a rich low temperature combustion mode.

7 Yet another feature of the method for simultaneous lean NO_x trap sulfur
8 removal and Diesel particulate filter regeneration, in accordance with the present
9 invention includes determining that the engine is operating in a predefined medium
10 or high load region of the engine operating range and then operating the engine in
11 alternately lean and rich combustion modes, wherein the lean combustion mode
12 may be either standard Diesel or lean premixed charge compression ignition
13 combustion and the rich combustion mode is provided by rich pre-mixed charge
14 compression ignition combustion.

15 BRIEF DESCRIPTION OF THE DRAWINGS

16 A more complete understanding of the method for simultaneously removing
17 sulfur from a lean NO_x trap and regenerating a Diesel particulate filter may be had by
18 reference to the following detailed description when taken in conjunction with the

1 accompanying drawings, wherein:

2 Fig. 1 is a somewhat schematic illustration of a typical Diesel engine suitable
3 for the purpose of illustrating the method embodying the present invention;

4 Fig. 2 is a graphical illustration of the air/fuel ratio control to provide high lean
5 NO_x trap and Diesel particulate filter temperatures in accordance with the present
6 invention;

7 Fig. 3 is a graphical illustration of the use of alternating lean low temperature
8 combustion and rich low temperature combustion for simultaneous lean NO_x trap
9 desulfation and DPF regeneration; and

10 Fig. 4 is a graphical representation of alternating pre-mixed charge
11 compression ignition lean and rich combustion control operation for lean NO_x trap
12 desulfation and Diesel particulate filter regeneration in accordance with the present
13 invention.

14 DETAILED DESCRIPTION OF THE INVENTION

15 As discussed above, low temperature combustion (LTC) and pre-mixed charge
16 compression ignition (PCCI) are alternative modes of combustion other than
17 conventional Diesel combustion. Both LTC and PCCI combustion modes can provide
18 the high temperature requirements for aftertreatment device regeneration, while

1 minimizing smoke generation maintaining low NO_x emissions.

2 Lean and rich operation can be provided in both LTC and PCCI combustion
3 modes. Lean operation, i.e., a mixture of intake air and fuel that is leaner than a
4 stoichiometric mixture (an ideal air-to-fuel mixture at which all of the air and all of the
5 fuel are consumed during the combustion process), is typical of normal Diesel
6 operation Rich operation, i.e., an air-to-fuel mixture richer than stoichiometric,
7 can be provided by throttling the intake air, increasing the exhaust gas recirculation
8 (EGR) rate and varying turbocharger operation. There are various methods for
9 injecting the additional fuel necessary to provide rich operation and control intake
10 throttle, exhaust gas recirculation, and turbocharger operation. The "air-to-fuel ratio"
11 (air/fuel ratio or simply A/F ratio) as used herein refers to the combustible mixture of
12 air and fuel present in a combustion chamber either prior to, during, or immediately
13 after combustion, and may consist of one or more components including ambient air,
14 recirculated exhaust gas, and compressed air provided by the compressor stage of a
15 turbocharger.

16 In the preferred embodiment of the present invention, alternating rich and
17 lean low temperature combustion modes when operating under low to light load
18 engine conditions, provide the required high lean NO_x trap and Diesel particulate

1 filter regeneration temperature as well as a rich exhaust gas mixture for desulfation
2 of the LNT. Under medium to high load engine operating conditions, alternating rich
3 pre-mixed charge compression ignition combustion (a stoichiometric or richer A/F
4 ratio) and either normal Diesel or PCCI lean combustion provide the required high
5 lean NO_x trap and Diesel particulate filter temperatures along with providing a rich
6 exhaust for sulfur removal.

7 A conventional Diesel engine 10 is schematically represented in Fig. 1, and
8 will be used in the following discussion of the method for simultaneously removing
9 sulfur from a lean NO_x trap and regenerating a Diesel particulate filter in accordance
10 with a preferred embodiment of the present invention. The Diesel engine 10 is
11 equipped with a turbocharger 12 that has a turbine stage 14 driven by exhaust gas
12 and coupled to a compressor stage 16 for the purpose of compressing intake air prior
13 to introduction into the engine. Also, the engine 10 has a Diesel particulate filter 18
14 disposed downstream of the turbine stage 14 and a lean NO_x trap 20 positioned
15 downstream of the Diesel particulate filter 18. A flow of compressed intake air is
16 directed through an intake conduit 22 to an intake port 24 of the engine 10. Fuel is
17 introduced into a combustion chamber 26 having a piston 28 by a fuel injector 30.
18 After combustion of a controlled air/fuel (A/F) mixture in the combustion chamber

26, exhaust gas is directed through an exhaust port 32 to an exhaust gas conduit 34 in controlled communication with the turbine stage 14 of the turbocharger 12. An exhaust gas recirculation (EGR) system 36 provides communication between the exhaust conduit 34 and the intake conduit 22 to recirculate controlled amounts of exhaust gas back into the intake air introduced into the engine. Exhaust gas flow through the EGR system 36 is controlled by an exhaust gas recirculation valve 38.

The engine 10 desirably has an intake air mass flow sensor 40, or other means for measuring intake air mass flow, disposed upstream of the compressor stage 16, and temperature sensor 42 disposed in the exhaust conduit 34 at a position upstream between the exhaust port 32 and the turbine stage 14 of the turbocharger 12. Additional temperature sensors 46 and 48 are arranged to respectively sense the internal, i.e., substrate or other, temperature of the Diesel particulate filter 18 and the lean NO_x trap 20. Additionally, a crankshaft position sensor 50 provides crankshaft position and engine speed signals to a conventional programmable electronic engine control unit (ECU) 52. The intake air mass flow sensor 40, the pre-turbine exhaust gas temperature sensor 42, the post-turbine exhaust gas temperature sensor 44, and the DPF and LNT temperature sensors 46, 48 are in electrical communication with the programmable ECU 52. In response to

1 sensed signals, as described below in greater detail, the programmable ECU 52
2 provides output signals to the fuel injector 30, the turbocharger 12, and the exhaust
3 gas recirculation control valve 38.

4 In a preferred embodiment of the present invention, a requirement for sulfur
5 removal from the LNT 20 is determined, for example, after a predetermined length of
6 time of operation or by a suitable sensor, not shown, positioned downstream of the
7 LNT. When it is determined that sulfur removal is required, the engine control
8 module 52 determines the desired modes for respective alternating rich and lean
9 combustion modes, that is, either normal Diesel, low temperature combustion or pre-
10 mixed charge compression ignition combustion. The determination for the desired
11 combustion modes is primarily based on engine load and speed, parameters which
12 can be at least partially provided by the intake air mass flow sensor 40, the injected
13 fuel mass, and the crankshaft position sensor 50.

14 As illustrated in Fig. 2, the engine is then temporarily operated alternately
15 between the desired rich and lean combustion modes for a selected length of time.
16 Exhaust gas produced during the alternating periods of lean combustion contain
17 excess oxygen (oxygen not consumed during combustion) and, in the high
18 temperature exhaust environment provided in accordance with the present invention,

1 oxidizes particulate matter trapped in the Diesel particulate filter 18. During the
2 alternating periods of rich combustion, the amount of excess air, if any, is minimized
3 and the lean NO_x trap 20 is desulfated and regenerated. As illustrated in Figs 3 and
4 4, the DPF and LNT temperatures are maintained at a high temperature so that the
5 respective regeneration and desulfation processes are advantageously
6 simultaneously carried out during the alternating periods of lean and rich operation.

7 The duration and frequency of respective operation in the lean and rich
8 combustion modes, and the respective lean and rich air/fuel ratios, and accordingly
9 the mean air/fuel ratio, are controlled based on the temperature feedback signal
10 from the temperature sensor 48 sensing the substrate temperature in the lean NO_x
11 trap 20. As illustrated in Fig. 2, it can be seen that the lean air/fuel ratio decreases
12 during the alternating periods of rich combustion and increases during the
13 alternating periods of lean combustion. Also, it can be seen that the substrate
14 temperature of the lean NO_x trap 20 and the Diesel particulate filter 18 decreases
15 during alternating periods of lean combustion and increases during alternating
16 periods of rich combustion.

17 Thus, the high lean NO_x trap and Diesel particulate filter temperatures
18 required for removal of sulfur from the lean NO_x trap 20 and regenerate the Diesel

1 particulate filter 18 are provided by controlling the immediate and mean air/fuel
2 ratios, and the duration and frequency of the respective periods of lean and rich
3 combustion operation.

4 The pre-turbine exhaust gas temperature, sensed by the temperature sensor
5 42, provides a convenient safety control to limit the maximum equivalence ratio, both
6 during rich and lean combustion, and the maximum pulse duration and frequency of
7 rich combustion to avoid exceeding a temperature that could damage the turbine 14
8 or other downstream components. Moreover, the mean value of the A/F ratio during
9 operation in the respective alternating lean and rich operation modes may be
10 calculated by the engine control module 52 and used as input for the control logic to
11 control fuel, exhaust gas recirculation, and air flow. By controlling the mean air/fuel
12 ratio, the temperature gradient across the Diesel particulate filter and the lean NO_x
13 trap can be limited.

14 Fig. 3 graphically illustrates engine operation in a defined relatively low, or
15 light, load operating region of the engine in which low temperature combustion is
16 desirably used for lean and rich operation. The substrate temperature of the lean
17 NO_x trap 20 is used as a feedback signal for closed-loop control of the lean, rich, and
18 mean A/F ratios, and pulse duration and frequency of operation in the respective

1 lean and rich combustion modes. Under very light load operation, the engine-out
2 temperature is low, for example, on the order of 100°C to 200°C. Therefore, the
3 alternating periods of lean and rich combustion must be carried out at a relatively
4 high frequency to maintain the exothermic reactions in the DPF 18 and LNT 20 and
5 increase the exhaust stream temperature discharged from the DPF.

6 When operating in predefined medium to high engine loads in which rich
7 pre-mix charge compression ignition combustion is desired, the lean NO_x trap
8 substrate temperature is also used as a feedback signal for closed-loop control of the
9 lean, rich, and mean A/F ratios, and the duration frequency of the respective lean
10 and rich combustion operating modes. As illustrated in Fig. 4, the pre-turbine
11 temperature, sensed by the temperature sensor 42, disposed in the exhaust conduit
12 34 upstream of the turbine section 14, is also used as a feedback signal for adjusting
13 the fuel injection parameters so that the pre-turbine temperature will not exceed the
14 maximum working temperature of the turbocharger 12. Under higher loads, the
15 engine-out exhaust gas temperature is much higher than at low loads. Therefore, the
16 rich periods of alternating lean and rich combustion are carried out at a lesser
17 frequency and for a shorter duration.

18 Thus, in accordance with the present invention, when it is determined that

1 sulfur accumulations stored in the lean NO_x trap needs to be reduced, or removed,
2 the desired rich combustion mode, i.e., for example LTC or PCCI combustion, is
3 determined by the engine control unit 52. The sensed substrate temperature of the
4 lean NO_x trap 20 is used to control the lean, rich, and mean A/F ratios, as well as the
5 duration and frequency of the respective lean and rich combustion modes. The
6 engine is alternately operated in the desired rich and lean combustion modes for
7 respective predefined periods of time and at a frequency and duration sufficient to
8 increase the mean substrate temperature of the lean NO_x trap 20 to a temperature at
9 which the sulfur accumulations stored in the lean NO_x trap 20 is reduced and the
10 Diesel particulate trap 18 is simultaneously regenerated. The pre-turbine exhaust
11 gas temperature, sensed by the sensor 42, is used to regulate the A/F ratio and the
12 frequency and duration of time in the respective alternating rich and lean
13 combustion modes to prevent the sensed temperature of the exhaust gas prior to
14 passing through the turbine stage 14 from exceeding a predefined value to prevent
15 thermal damage to the turbocharger 14 or other engine component.

16 When it is determined that the engine 10 is operating in a predefined low
17 load region of the engine operating range, it may be alternately operated in a
18 respective lean low temperature combustion mode and a rich low temperature

1 combustion mode.

2 When it is determined that the engine 10 is operating in either a predefined
3 medium or high load region of the engine operating range, the engine may be
4 operated alternately in either a standard Diesel or in a lean pre-mixed charge
5 compression ignition combustion mode, and a rich pre-mixed charge compression
6 ignition combustion mode.

7 Importantly, when operating in any of the determined operating modes, the
8 frequency and pulse duration of the respective combustion modes and air/fuel ratio
9 is modified in response to the sensed value of the substrate temperature of the lean
10 NO_x trap to provide a high exhaust gas temperature that is sufficient for LNT
11 desulfation and DPF regeneration.

12 Moreover, if desired for the purpose of providing an exhaust gas temperature
13 to heat the substrate of the lean NO_x trap 20 to a desired high temperature, the
14 engine may be alternately operated respectively in either a standard Diesel
15 combustion mode and a lean pre-mixed charge compression ignition combustion
16 mode or a standard Diesel combustion mode supplemented by the post-injection of
17 fuel.

18 In the above discussion of the present invention in which the substrate

1 temperature of the lean NO_x trap if provided to a programmable electronic engine
2 control unit for the purpose of controlling A/F ratio and the duration and frequency of
3 the respective alternating lean and rich combustion modes, it should be recognized
4 that the substrate temperature of the lean NO_x trap can be used by the
5 programmable electronic engine control unit to modify or control other engine
6 operating parameters, such as the exhaust gas recirculation rate and the amount of
7 boost provided to the intake air by the compressor stage 16 of the turbocharger 12.

8 From the above description, it can be seen that by controlling the frequency,
9 pulse duration and A/F ratio of respective alternating lean and rich combustion, that
10 the temperature and composition of the exhaust gas can be controlled in a manner
11 such that the desulfation of the lean NO_x traps and regeneration of the Diesel
12 particulate filters can be carried out simultaneously. Low temperature combustion
13 and pre-mixed charge compression ignition modes are the preferred combustion
14 modes to provide the very high mean temperatures required to remove sulfur from
15 the LNT and regenerate the DPF.

16 The present invention is described above in terms of a preferred illustrative
17 embodiment in which those skilled in the art will be able to readily determine the
18 desired air/fuel ratio as well as the duration and frequency of respective operation in

1 the selected lean and rich combustion modes. Also, although Lean NO_x trap
2 substrate temperature is used in the illustrative example to control respective lean
3 and rich combustion, other appropriate temperature measurements, such as lean
4 NO_x trap inlet temperature, could be used in carrying out the present invention.

5 Other aspects, features and advantages of the present invention may be
6 obtained from a study of this disclosure and the drawings, along with the appended
7 claims.

CLAIMS

What I claim is:

1. A method for simultaneous removal of sulfur from a lean NO_x trap and regeneration of a Diesel particulate filter of a Diesel engine equipped with a turbocharger, said method comprising:

determining a need to reduce sulfur accumulations stored in said lean NO_x trap;

determining a desired rich combustion mode for temporary operation of the engine;

sensing the substrate temperature of said lean NO_x trap;

sensing the temperature of exhaust gas prior to the exhaust gas passing through a turbine stage of said turbocharger; and

alternatingly operating said engine in a lean combustion mode and said desired rich combustion mode for respective predefined periods of time, said respective periods of time being of a frequency and duration sufficient to increase said substrate temperature of the lean NO_x trap to a temperature at which said sulfur accumulations stored in the lean NO_x trap are reduced and said Diesel particulate trap is simultaneously regenerated.

1 2. The method for simultaneous removal of sulfur from a lean NO_x trap and
2 regeneration of a Diesel particulate filter, as set forth in Claim 1, wherein said
3 method includes controlling the air/fuel ratio and the frequency and duration of time
4 of operation in said alternating lean and rich operating modes to prevent the
5 temperature of the exhaust gas prior to passing through the turbine stage from
6 exceeding a predefined value.

7
8 3. The method for simultaneous removal of sulfur from a lean NO_x trap and
9 regeneration of a Diesel particulate filter, as set forth in Claim 2, wherein said
10 predefined value of temperature of the exhaust gas passing through the turbine
11 stage is the maximum working temperature of the turbocharger.

1 4. The method for simultaneous removal of sulfur from a lean NO_x trap and
2 regeneration of a Diesel particulate filter, as set forth in claim 1, wherein said
3 determining a desired rich combustion mode for temporary operation of the engine
4 includes determining that said engine is operating in a predefined low load region of
5 the engine operating range, and said alternately operating said engine in a lean
6 combustion mode and said desired rich combustion mode includes alternately
7 operating said engine respectively in a lean low temperature combustion mode and a
8 rich low temperature combustion mode.

9
10 5. The method for simultaneous removal of sulfur from a lean NO_x trap and
11 regeneration of a Diesel particulate filter, as set forth in claim 1, wherein said
12 determining a desired rich combustion mode for temporary operation of the engine
13 includes determining that said engine is operating in one of a predefined medium
14 and high load region of the engine operating range, and said alternately operating
15 said engine in a lean combustion mode and said desired rich combustion mode
16 includes alternately operating said engine respectively in one of a standard Diesel
17 combustion mode and a lean pre-mixed charge compression ignition combustion
18 mode when lean combustion mode is desired, and in a rich pre-mixed charge

1 compression ignition combustion mode when rich combustion is desired.

2
3 6. The method for simultaneous removal of sulfur from a lean NO_x trap and
4 regeneration of a Diesel particulate filter, as set forth in claim 5, wherein the
5 frequency and duration of said respective periods of time and the air/fuel ratio
6 during the respective periods of time is modified in response to the sensed value of
7 the substrate temperature of said lean NO_x trap.

8
9 7. The method for simultaneous removal of sulfur from a lean NO_x trap
10 and regeneration of a Diesel particulate filter, as set forth in claim 1, wherein said
11 determining a desired rich combustion mode for temporary operation of the engine
12 includes determining that said engine is operating in one of a predefined medium
13 and high load region of the engine operating range, and said alternately operating
14 said engine in a lean combustion mode and said desired rich combustion mode
15 includes alternately operating said engine respectively in one of a standard Diesel
16 combustion mode and a lean pre-mixed charge compression ignition combustion
17 mode when lean combustion is desired, and in one of a standard Diesel combustion
18 mode and a pre-mixed charge compression ignition combustion mode, either of

- 1 which may be supplemented by the post injection of fuel when rich combustion is
- 2 desired.

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2

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8. The method for simultaneous removal of sulfur from a lean NO_x trap and
regeneration of a Diesel particulate filter, as set forth in claim 1, wherein said method
includes providing said sensed substrate temperature of the lean NO_x trap to a
programmable electronic engine control unit and adjusting at least one engine
operating parameter in response to the sensed substrate temperature.

8

9

9. The method for simultaneous removal of sulfur from a lean NO_x trap and
regeneration of a Diesel particulate filter, as set forth in claim 1, wherein said method
includes controlling the mean air/fuel ratio to control the temperature and the
temperature across said lean NO_x trap and said Diesel particulate filter.

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ABSTRACT OF THE DISCLOSURE

3

High exhaust gas temperatures whereby sulfur is removed from a lean NO_x

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traps simultaneously with regeneration of a Diesel particulate filter is provided by

5

alternating engine operation in respectively defined lean and rich combustion

6

modes. The duration and frequency of the respective lean and rich operating modes,

7

as well as the air/fuel ratio during the respective modes, are preferably controlled by

8

the sensed temperature of the lean NO_x trap substrate.

Fig. 1

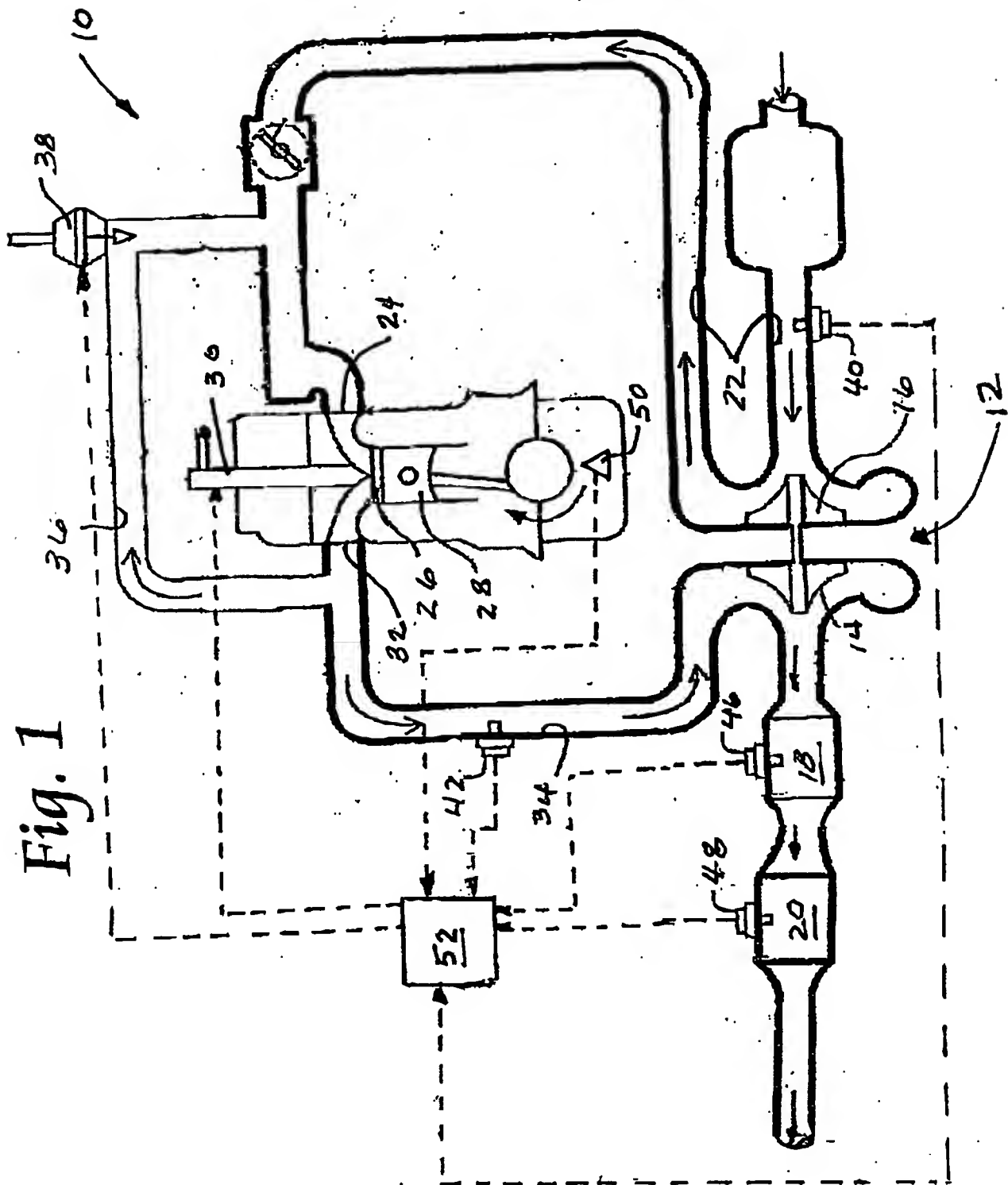


Fig. 2

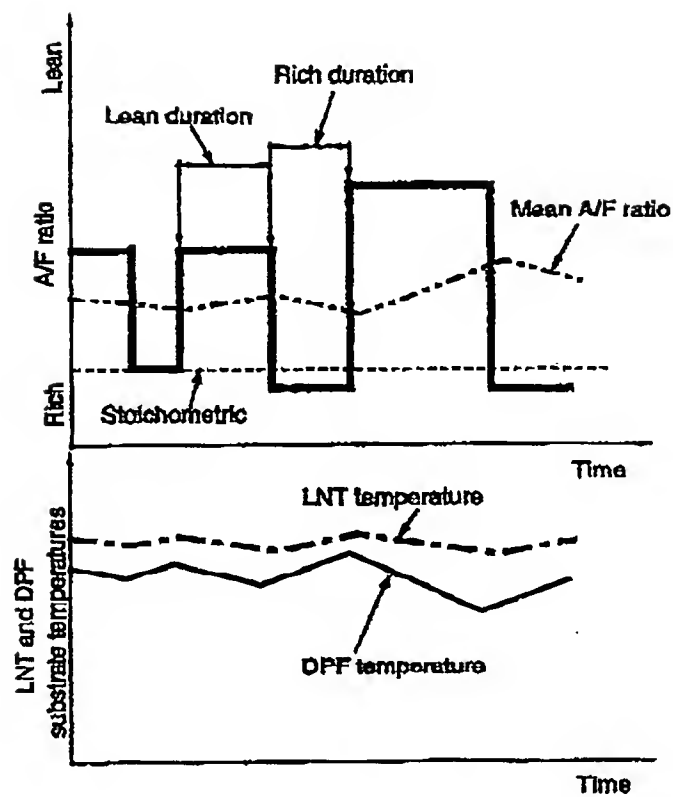


Fig. 3

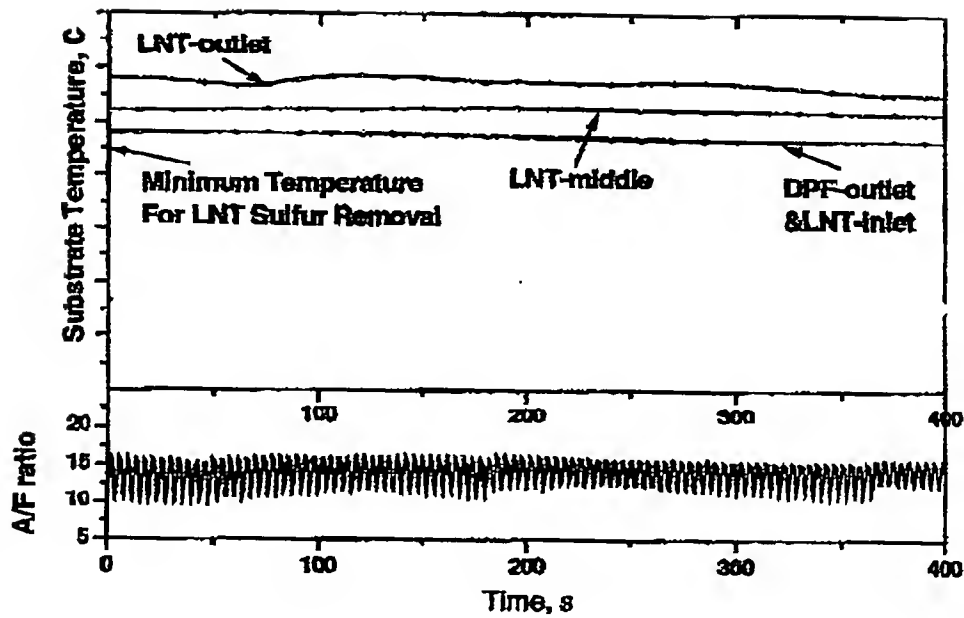


Fig. 4

